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ANALYSIS FOR THE DESIGN OF A U.S. NAVY DIVING AND SALVAGE SMART STAGE

by

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June 2013

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13. ABSTRACT (maximum 200 words)

The Navy's Dive and Salvage community is in need of a new dive stage, called the SMART Stage, which will increase the productivity and safety of its users along with matching their capabilities to that of the commercial industry. The existing dive stage is a stainless steel cage that merely transports divers and their tools from the surface towards the worksite at a maximum depth of 300 feet. What modifications and improvements can be made to make the divers safe? Improve productivity? Should this new stage be comprised of commercial off-the-shelf parts or can it be purchased as a pre-fabricated system? This thesis will investigate what is needed to improve the safety and productivity for the community as well as the possible design alternatives of a SMART Stage. This study will perform the Systems Engineering process by carrying out a stakeholder needs' analysis to help define the functions and requirements that must be met by the SMART Stage.

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ANALYSIS FOR THE DESIGN OF A U.S. NAVY DIVING AND SALVAGE SMART STAGE

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ABSTRACT

The Navy's Dive and Salvage community is in need of a new dive stage, called the SMART Stage, which will increase the productivity and safety of its users along with matching their capabilities to that of the commercial industry. The existing dive stage is a stainless steel cage that merely transports divers and their tools from the surface towards the worksite at a maximum depth of 300 feet. What modifications and improvements can be made to make the divers safe? Improve productivity? Should this new stage be comprised of commercial off-the-shelf parts or can it be purchased as a pre-fabricated system? This thesis will investigate what is needed to improve the safety and productivity for the community as well as the possible design alternatives of a SMART Stage. This study will perform the Systems Engineering process by carrying out a stakeholder needs' analysis to help define the functions and requirements that must be met by the SMART Stage.

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LIST OF ACRONYMS AND ABBREVIATIONS

00C	Office of the Director of Ocean Engineering, SUPSALV
COMMS	Communications
CONEX	Another Name for a Shipping Container
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
ESSM	Emergency Ship Salvage Material
LARS	Launch and Recovery System
GPC	Government Purchase Card
MDSU2	Mobile Dive and Salvage Unit 2
NAVSEA	Naval Sea Systems Command
OJT	On the Job Training
SME	Subject Matter Expert
SUPSALV	Supervisor of Salvage and Diving

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EXECUTIVE SUMMARY

The U.S. Navy is in need of a new diving stage for the Diving and Salvage Units. The current models, which are only capable of transporting divers and equipment to the salvage sites, are functionally limited to the divers and supervisors. These units and their personnel have expressed a need for something that allows better monitoring of the worksite and improves the safety of the divers. This new system will be called SMART Stage, which will be a modular stage that can be utilized in all areas that the divers operate with the current model.

The Systems Engineering process and modeling was used throughout this thesis to aid in developing the solutions. This process consisted of an extensive research on the current dive stage in use today, a detailed analysis of the stakeholders and their needs, along with defining the functions and requirements of the SMART Stage.

From the analysis conducted within this thesis it has been determined that the SMART Stage must include several critical components. These components are: stage mounted lights, an umbilical feed to the divers from the ship, acoustic topographic transceiver, helmet mounted camera, stage mounted camera, pressure sensor on stage, a current sensor attached to stage which transfers data back to the supervisor, and a temperature sensor that is also attached to stage and transfers data back to the supervisor.

There were four pre-fabricated stage systems analyzed and none of them alone contained the components needed to meet the requirements set for the SMART Stage. Of the four, only two were able to achieve the U.S. Navy Divers operational depths and the only benefit these systems possess are their mobility and inclusion of a crane that is separate from what the salvage ships provide. Another option is a SMART Stage system that is comprised of commercial off-the-shelf (COTS) parts that are either installed onto the current dive stages used today or one of the two pre-fabricated dive stages. Each of the following COTS parts map to one of the recommended components of the SMART Stage: the Snooper III, Fibron Umbilical, Tritech SeaKing Hammerhead, Kongsberg

Maritime OE14-522, Paroscientific 181KT, Valeport Model 803 ROV Electromagnetic current meter, and the Paroscientific 181KT.

In addition to the commercial off-the-shelf parts, a CONEX Box, another name for standard shipping container, will serve as the command center for the dive supervisor. This command center will house the various monitors used to observe the worksite, divers', and sensors installed on the stage as well as function as a locker for the divers gear and tools. Extra sources will be utilized to serve as a backup which will create a redundancy for the SMART Stage. These extra sources are: color-coded chains to help identify the depth of the stage and an ARGO that will be utilized to help provide additional information of the temperature at various depths. The power sources for the tools are provided by separate pumps and generators that will be housed in the command center. Additional features, hose reel and/or tool box, could be added to the stage; which would allow the divers access to other tools not otherwise known ahead of time to complete a task at hand if it emerges during the mission.

I. INTRODUCTION

When the U.S. or its Allies have items that need to be salvaged or constructed in the depths of the water, they send in the U.S. Navy divers to carry out that task. The current device used to transport these divers to the site is called the "3 Man Decompression Diving Stage," but is simply referred to as "dive stage or stage" within the dive community. With a rising concern for diver's' safety and the desire to increase the capabilities of the Navy dive community to match the capabilities of the commercial industry, a new dive stage is being requested. There are certain attributes that the U.S. Navy requires from the new dive stage; the majority of these features are to make the stage a tool that not only will transport the divers and their equipment to the work site but a tool that can provide valuable information for the observers and supervisors topside. This new diving stage will be called SMART Stage.

The current models are bare bones with only limited functionality as a platform that transfers the divers and their tools and from the worksite. These stages are located on Navy salvage vessels and utilize a crane to raise and lower the stage. The Navy is requesting that a cost-benefit analysis be performed to compare the integration of commercial off-the-shelf diving and salvage products into one system versus the purchase of pre-fabricated stages. This thesis will serve as an investigation into possible design alternatives of a SMART stage dive cage against the existing dive stage including Commercial Off-the-Shelf (COTS) equipment.

This study will use a Systems Engineering approach including modeling to aid in defining what the actual problem is for the Navy and methods/solutions needed to solve that problem. The systems approach used will also help the program manager and the program team to understand the activities and logical decision points. The selected model for this thesis is the Systems Vee model (see Figure 1), utilized throughout the project.

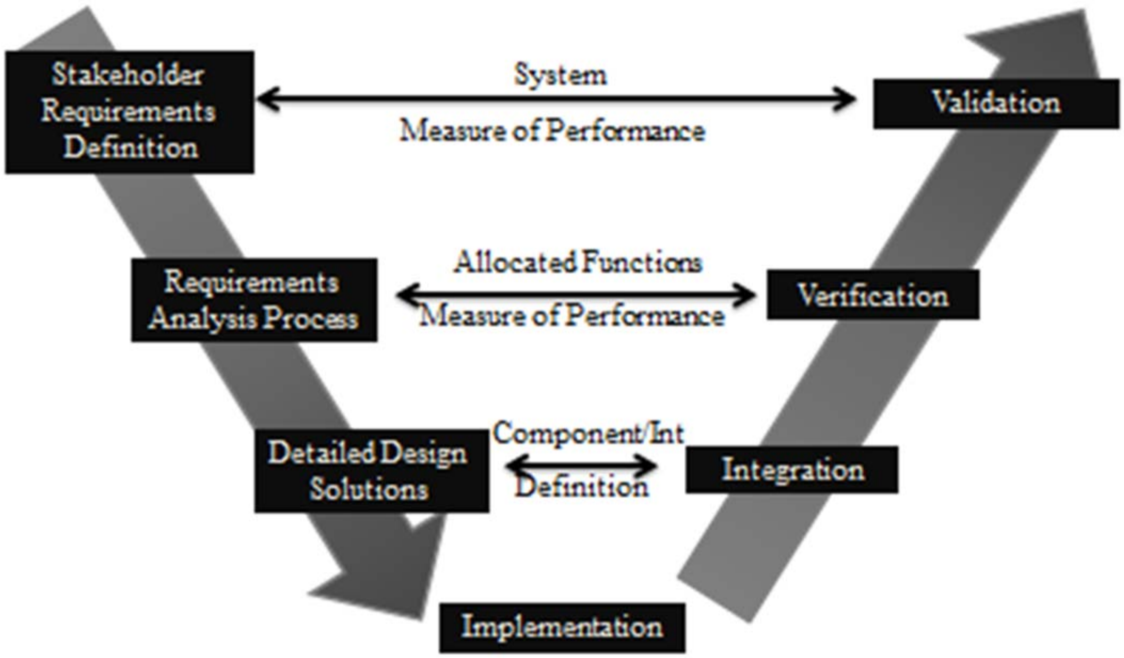

Figure 1. General Vee Model (After Blanchard and Fabrycky 2011)

This thesis focuses on the “down stroke” of the Vee model; starting with the stakeholder requirements definition, the study will flow through requirements analysis process and ultimately arrive at a detailed design solution. Knowing that the SMART Stage may be built in the near future, any actual process would have to be standardized and documented to ensure proper communication for follow on analysis. A project manager and/or contractor would be able to implement the design and complete the “upstroke” of the Vee model.

II. DEFINING THE PROBLEM

A. BACKGROUND INFORMATION

Prior to designing the SMART stage, background research was needed on the current system used by the Navy divers. The background research evaluated the work environment in which the divers would operate and use the system, as well as, the specifications and design of the current dive stage.

1. Work Environment

The divers' work environment and conditions of the waters vary depending on the location and situation in which they are called upon to act. A dive stage is used when a diver is conducting decompression diving. Decompression diving is the process of diving underwater without a protective pressurized container, i.e., mini-submarine or dive bell. This means that the diver is open to the environment and subjected to the pressure placed upon the body. The current dive stage may be used in tropical waters for one salvage job, and then the next time it is used may be in frigid arctic waters (Commander, Naval Sea Systems Command 2011). At times the salvage site may be contaminated with oil or other toxins and then the next site will be clear pristine water. For each of the various missions, the divers are equipped with the proper protective equipment and the dive stage is built from a material that can handle the various demanding conditions needed to accomplish the mission. There is one situation when the divers are unable to use the existing dive stage: water current at the salvage site exceeds 3 knots (Commander, Naval Sea Systems Command 2011).

2. Current Stage Model

The company that designed and fabricated the current stage model being used is Emergency Ship Salvage Material (ESSM). These stages are constructed from stainless steel, which is beneficial because that metal is capable of operating in the various climate conditions the divers' are employed; however, they only have a life span ranging from 10–20 years. The large range in life span is due to how frequently the stage is subjected

to salt water and whether they are maintained properly after each use. The stages are open cages which expose the diver to the environment. Normally 2 divers are transported to the salvage site, but the stage is able to transport up to 3 divers and their equipment (Commander, Naval Sea Systems Command 2011). The stage can carry a load up to 2700 pounds, which includes the divers and the equipment. Appendix A depicts a detailed drawing and schematics of the dive stage being used today. The procurement of these stages began with a statement of work from MDSU2 to ESSM then there was a delivery order from NAVSEA 00C to GPC Joint Venture.

B. STAKEHOLDER ANALYSIS

With the completion of the background research, development of the problem statement may begin. The first part in defining the problem is to identify the various stakeholders' and their needs and objectives for this system. The initial list of stakeholders and their needs and objectives were developed using the growing understanding of the issue through discussions with the thesis advisors and Navy divers. The information gathered was about what the dive stage should be able to do, and no personally identifying information was needed or recorded in these stakeholder need discussions. The first part in this analysis was to identify all of the various organizations that have some sort of interaction with the current dive stage and who may have some interactions with the SMART Stage. Once they had been identified the next step of the process was to list their needs desired from the SMART Stage. The final step was to convert the stakeholders' needs into objectives.

A portion of the stakeholders' needs and objectives was identified by having teleconferences with Navy divers who proposed this need for a new stage and also with other Navy divers who were not aware of the creation of a new dive stage. These identified needs are later translated into functional requirements for the SMART Stage. All stakeholders and their needs could not be satisfied and in order to properly scope the research. The list of stakeholders is prioritized based on their impact/need of the SMART Stage and the information that was available. The comprised list of stakeholders, their needs, and the objectives that SMART Stage is required to meet is in Table 1.

Table 1. Stakeholder Analysis

	Stakeholder	Needs	Objectives
Primary Users	Navy Divers	Additional lighting	Have increased lighting in the workspace in order to work more efficiently and safely
		Reduction in tools/hoses hanging from the ship	Easily assessable tools from the stage and less clutter in the work space will help provide a safe workspace
		Easier access for tools and hoses	
	Navy Dive Supervisor	Knowledge of stage location	To have an accurate depth reading of the stage to ensure the divers are operating in the legal depths
		To ensure that the divers are safe	Have increased surveillance and knowledge of the divers and worksite
		Have an overview of the worksite	Provide a safe work environment for the divers
Secondary Users	Naval Diving and Salvage Training Center	Something that does not require extensive training for present and future divers	Maintain mission readiness without sacrificing training
		Minimal additions to the tools divers take with them	Provide an efficient workspace for the divers to meet the mission
	Salvage Ships	Stage to be interoperable with the different classes of salvage ships	Maintaining current mission readiness and use of vessels without much changes to the vessels
	Shipyards	Stage that is easily movable to different locations	Reduce setup times and increase productivity in order to move ships out of the yards
		Want to ensure that the divers are safe	Maintain/improve shipyard safety ratings

	Stakeholder	Needs	Objectives
	Downed vessels	Effective means for salvage	Ensuring the divers have the tools necessary to complete the mission
	SMART Stage Manufactures	Provide the U.S. Navy with a quality stage	Capture a portion in the stage construction industry
		Have the stage meet the requirements and budget on time	Remain profitable
Sponsors	NAVSEA	Provide a stage that is safe	Reduce spending on new equipment without reducing safety requirements
		Low purchase cost and maintenance cost	
	SEA 00C2 Office of the Director of Ocean Engineering also known as Supervisor of Salvage and Diving (SUPSALV)	Provide a safe stage for divers	Maintain/increase the divers' safety record
		Provide extra monitoring ability for dive supervisors	Increasing the capability of the supervisors roll and ensure the safety of divers
		Stage that is easily movable to different locations	Maintaining current operational use of stages without having to change too much of how divers operate
		Stage that is interoperable with the different classes of salvage ships in use today	
		Increase productivity from divers and crew	Providing a safe environment for divers that is also efficient should increase the productivity of the divers

As previously stated, these stakeholders were identified as personnel or organizations that will have interactions with the development of the SMART Stage. They were classified into three categories: Primary user, secondary user, and sponsor.

The primary users are those who will interact with the SMART Stage on a daily basis and will have direct contact with the stage post-development; they are the ones for whom the SMART Stage is being developed. The secondary users are the stakeholders who will either transport or benefit from the primary stakeholders' use of the SMART Stage. Lastly, the sponsors are the ones who have a vested interest in the development of the SMART Stage due to their funding as well as being the beneficiaries of the increased productivity from and safety of the primary users.

C. ASSUMPTIONS, LIMITATIONS, CONSTRAINTS

Having a good understanding of the various limitations and constraints imposed on the new system will improve the probability of a SMART Stage becoming a successful system. From the teleconferences held with the divers, training for the use of the current dive stage is not conducted at dive school, but it is held at the dive units once a member is a qualified diver. It is assumed that training for the SMART Stage will happen at the dive units and the initial instruction on the proper use will be provided by the manufactures and all follow-on training will continue as with the current process for new members of the community. A few other assumptions made are that the maintainers of the new stage will be the Navy divers and personnel in the units and that the stage will be compatible with the current ships.

The dive and salvage community has special funding for upgrades to existing equipment and can also use funds that are allocated for emergencies. The emergency fund is provided for the community to acquire equipment and tools needed for unexpected projects. However, a possible limiting factor for the SMART Stage is cost. With the government currently needing to reduce cost where ever possible, exemplified by the current sequestration, funding for new programs is limited. Furthermore, the increased volume of natural disasters and salvage projects that divers are called upon to conduct may have reduced the amount available in the emergency fund.

One constraint that is placed upon this project is the size and weight of the SMART Stage. The current stage is mobile and used on all of the salvage vessels that the Navy uses. The SMART Stage will also need to be mobile and interoperable among the

different vessels. This means that the new system is to be light weight and effective in meeting the needs and objectives of the stakeholders.

D. BOUNDARIES AND SCOPE

From the stakeholder analysis, there were several key stakeholders that arose; see Figure 2: the divers who will use the stage, the diving supervisors who will monitor and communicate with the divers, and the Supervisor of Salvage and Diving (SUPSALV) who will assist in funding the new stage. The scope of this thesis will involve them since they are providing the information and they have expressed interest in the design outcome. In the thesis they will have the role of regulators and architects and beneficiaries, providing assistance and guidance throughout the early system design phase. Once a solution/product has been determined, they will then have the role of supervising the construction and once the stage is fielded/issued to the units, they will then benefit from the usefulness of the new stage. The physical and geographical boundaries imposed for this study are the stage system which is to be mobile and operational on the various naval salvage vessels.

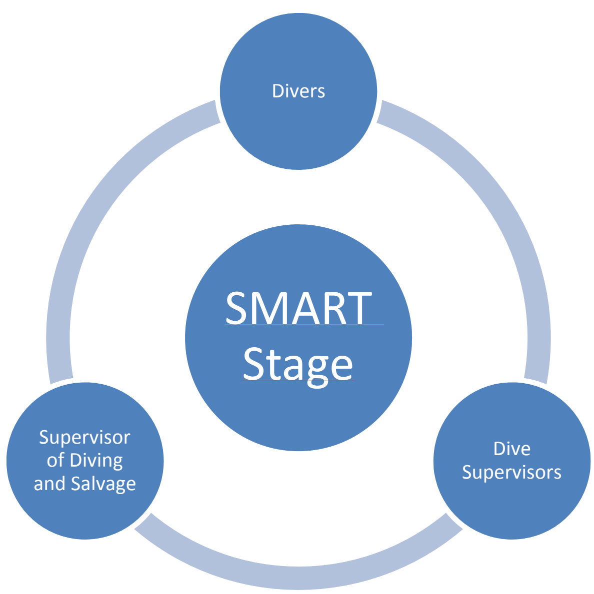

Figure 2. SMART Stage Key Stakeholders

This thesis will document the systems engineering approach towards achieving the final product to be delivered to the primary stakeholders, which will be a conceptual design and an investigation into possible design alternatives of a SMART stage dive cage against the existing dive stage including COTS equipment.

E. PROBLEM STATEMENT

The U.S. Navy is in need of a new diving stage for the Diving and Salvage Units. The current models, which are only capable of transporting divers and equipment to the salvage sites, are functionally limited for both the divers and supervisors. These units and their personnel have expressed a need for something that allows better monitoring of the worksite and improves the safety of the divers. This new system will be called SMART Stage, which will be a modular stage that can be utilized in all areas that the divers operate with the current model. This thesis will identify the needs of the stakeholders, the functions and requirements of the SMART Stage, what parts are needed to accomplish those functions within the requirements set, and whether the Navy should build the SMART Stage from COTS parts or purchase prefabricated systems.

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III. OPERATIONAL CAPABILITIES AND ACTIVITIES

The concept of the SMART Stage is to provide a safe and effective platform for divers to use while underwater at salvage sites as well as to provide the means for supervisors to observe the salvage site and oversee the divers for their safety. The concept of operations (CONOPS) that the system will follow is critical to understanding the context in which the SMART Stage will be designed. This section outlines the operational concepts, activities, and use cases of the SMART Stage.

A. CONCEPT OF OPERATIONS

The SMART Stage will need to operate and reach depths of 400 feet. The average maximum depth in which the divers will operate with the use of a stage is 300 feet. The purpose of having the stage being capable of operating up to 400 feet is to ensure that the stage is built to a standard that exceeds the normal use demanded by the divers. All of the sensors and equipment used on the stage will have to meet certification standards that rate them for operational use at depths of 400 feet.

The SMART Stage would be designed to be modular and adaptable to different missions. The stages used today are moveable and interoperable with the different salvage vessels, as well as, alongside a ship on a pier/platform. The SMART Stage will also be used on these vessels and the design and engineering of them will need to ensure that they are interoperable with the current ship system, yet modular so they can be updated to meet the different requirements for specific missions.

1. The SMART Stage Used for Salvage Missions

There are times when vessels have collided with reefs/rocks and either run aground or sunk to the ocean depths. This is one of the few typical missions that Navy divers are called upon, to help retrieve the sunken vessels or to disassemble it and remove the vessel from its location. During these missions, divers will work in stages at depths reaching no more than 300 feet. The divers may operate in areas with minimal light and to combat this they will need to have sufficient lighting for the area along with

handheld/helmet mounted lights to complete the task. Also the divers will need to ensure that their tools are easily accessible; since the stage is capable of holding up to 2700 pounds, a majority of the tools needed are transported with the divers on the stage. Having extra tool and storage attachments on the stage will provide a more efficient work environment for the divers. The supervisors will be able to monitor the divers' work, through the cameras, along with overseeing their safety. The supervisors are able to communicate with the divers and notify them if they see any safety hazards or receive pertinent information from the divers concerning the salvage site.

2. The SMART Stage Used for Underwater Construction/Repair Missions

In this mission, the SMART Stage will transport the divers and their tools towards the worksite, which is no deeper than 300 feet. During these types of missions the divers will utilize different tools from what are needed for salvage operations. Some of the tools are lowered with the divers and others are hanging from the surface. With tools and cables hanging from the surface, the worksite is cluttered and a potential safety hazard for the divers. Sufficient lighting and cameras are used to help guide the divers and keep them safe. At times divers may have to work alongside a vessel, while on the stage platform, and the supervisors need to ensure that the stage is placed in the correct location and that there is minimal movement due to the water's current. With supervisors having the ability to monitor these changes, they will have the ability to notify the divers and provide safe guidance for task completion.

3. The SMART Stage Used for Rescue/Reconnaissance Missions

In this mission, divers will be transported from the surface to the worksite via the SMART Stage, to carry out any rescue or reconnaissance missions requested by the Navy. There are situations when sunken vessels may have valuable equipment, items, or personnel still aboard that need retrieving. For these particular missions the divers may have to utilize salvage or construction tools in order to access the areas that house the objects. The divers will need adequate lighting while at the worksite in order to properly survey the area and cut/build anything needed for the retrieval. The supervisors will be able to survey the area and guide the divers to any findings they view from the cameras.

IV. SYSTEM FUNCTIONAL ANALYSIS

With a clear and concise understanding of how the SMART Stage will be utilized by the Navy Dive Community, along with identifying the involved stakeholders' needs and objectives, the system functional analysis can then take place. The top level functions are defined using high level terms because they encompass the stakeholders' needs; however, they are not too broad to be able to anchor the concept and understanding of the SMART Stage functions. The overarching function of the SMART Stage is to assist the divers in completing missions. The stage is not used for every mission that the Navy is employed on, however, when the stage is utilized, certain functions are needed to satisfy the stakeholders' involved.

A. FUNCTIONAL DECOMPOSITION

With the identification of what the overarching function is for the SMART Stage, the following functions, which branch out, are able to support the implementation of having a stage that will assist in desired missions (see Figure 3).

To Transport: The SMART Stage must be able to move the current weight in personnel and tools that the stage used today can accomplish. Not only does the SMART Stage move the personnel and their tools to the worksite, but also the system is easy for the ship's crew to help set up and ensure that operations topside are working properly.

To Provide Services and Monitoring: The SMART Stage will provide services for the divers while underwater and services for the supervisor's topside. These services will help keep the divers alive as well as deliver the power needed to run all the different tools and equipment. The SMART Stage will also provide monitoring capabilities for the supervisors, which will help ensuring that divers are operating in a safe environment.

To Sense: Is where the SMART Stage will be able to collect information of its surroundings and provide that data back to the dive supervisors so they are able to make the right decision.

Usability, Re-Use, and Reliability Maintainability Availability: These three are non-functional requirements that are needed to from the SMART Stage. They guarantee that the SMART Stage is sustainable and requires minimal training, which will not hinder the dive unit's mission readiness.

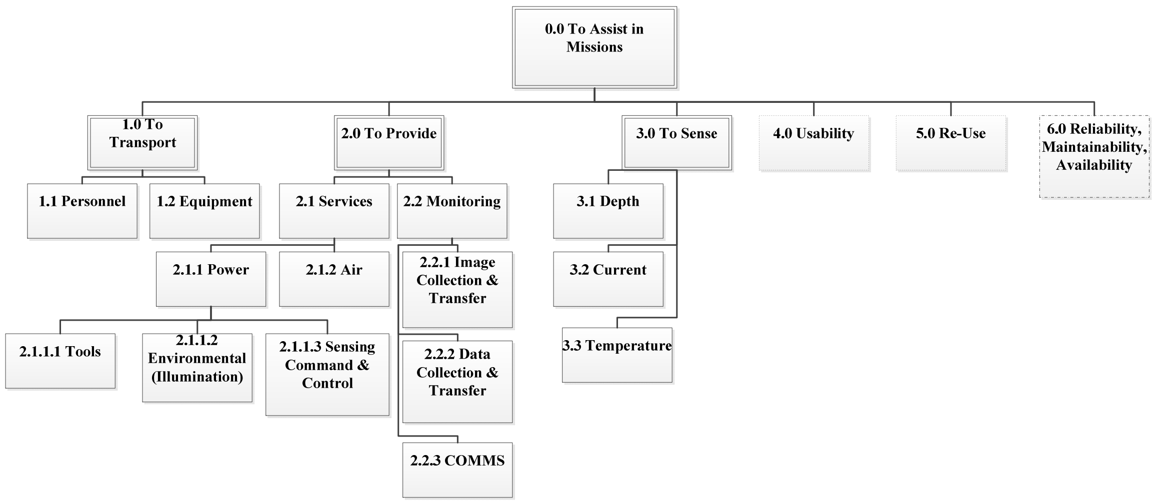

Figure 3. Functional Hierarchy

To support with keeping the problem and functions in scope, Table 2 defines each of these functions. These definitions not only keep the functions within a particular scope, but they also serve as a foundation for the generation of requirements that these functions must meet for the SMART Stage.

Table 2. Function Definition

Function	Definition
1	The various methods of positioning and moving the SMART Stage along with its accessories from the surface to the different oceans depths
1.1	The transportation of the divers from the surface to the underwater worksite
1.2	The transportation of the tools and equipment used by the divers and supervisors from the surface towards the worksite
2	The services and monitoring capabilities provided to the divers and supervisors
2.1	The air and power needed to operate the machinery and maintain the health of the diver
2.1.1	The different methods and strength of power output provided to the diver and supervisor to operate the tools and equipment.
2.1.1.1	The use of hydraulics or electrical or pneumatics as a means provided from the SMART Stage for the tools used
2.1.1.2	The power provided to help illuminate the underwater worksite
2.1.1.3	The power provided to ensure the operation of the sensing command and control
2.1.2	The air provided for the divers use
2.2	The different methods of receiving information about the worksite and well-being of the divers
2.2.1	The visual input/display of what is happening underwater
2.2.2	The statistical information and data provided by the SMART Stage of the worksite environment
2.2.3	Verbal communication between the divers and the supervisors
3	Knowing what the surroundings are of the worksite and status of the SMART Stage
3.1	Having constant feedback of the depth of the SMART Stage
3.2	Knowing what the water speed is at the depth of the worksite in order to ensure that the divers are kept safe
3.3	Knowing what the temperature is at the various depths to ensure that the divers are properly outfitted with the right equipment
4	That the SMART Stage is operable with minimal training for the divers and other users
5	That the SMART Stage is reusable and operable on the different platforms and locations that divers work at
6	That the SMART Stage is consistently reliable, easily maintainable, and readily available

B. FUNCTIONAL FLOW

Once the functions have been identified, the next step is to have an understanding of how the top level functions interact with each other to help form the main function of SMART Stage. The first function of the SMART Stage is to transport the personnel and their tools to the worksite, as shown in Figure 4. Once the personnel and the tools are transported, the SMART Stage will then provide the added safety needed for the divers along with feedback to the dive supervisors. The feedback provided to the supervisors is completed by the combination of the monitor and sense functions. The SMART Stage will sense/collect this information by the various array of sensors mounted upon the stage. These two functions, to provide services and monitoring and to sense, will work constantly and simultaneously with each other while the SMART Stage is employed. The final product produced with these three top level functions working together is the main function of "to assist" in missions.

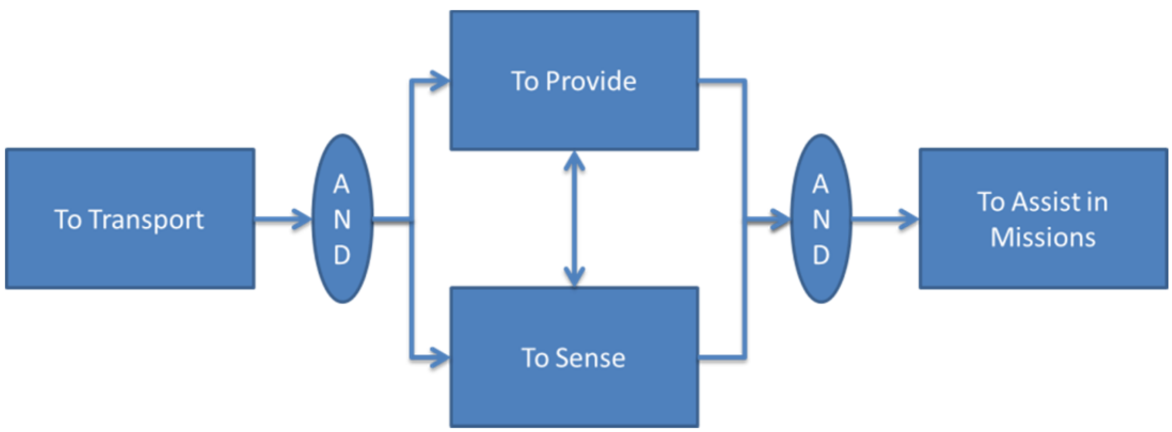

Figure 4. Functional Flow Block Diagram

V. REQUIREMENTS ANALYSIS

Once the analysis of the systems functions have been completed, the key requirements associated with how the problem will be solved can be determined. The data and inputs on the various limitations and constraints along with the needs of the stakeholders and the functions of the system all play a part in forming what the requirements will be for the SMART Stage. These requirements are mapped directly with the functions identified, and result in both functional requirements and non-functional requirements. The functional requirements describe the capabilities that must be met by the SMART Stage in-order to fully satisfy the needs of the operational functions of the system. The non-functional requirements are a constraint placed upon the SMART Stage that is independent of the functional requirements. Some of the metrics identified in both Tables 3 and 4 are subjective; many may need to be altered during the testing and developmental stages to ensure that the desired capabilities are being delivered to the stakeholders as more information is gathered during the design maturation process.

A. MEASURE OF EFFECTIVENESS

The measures of effectiveness (MOE), seen in Table 3, measures the operational capability of the system. In short, how well does it work in the intended operational modes? A MOE is assigned to the top level functions and have mission-oriented objectives.

Table 3. Requirements (Measure of Effectiveness)

Function ID	Function	Requirement	Requirement ID
0	To Assist In Missions	MOE: The SMART Stage shall be interoperable with various platforms	0.1
		MOE: The SMART Stage shall be transportable on various platforms.	0.2

Function ID	Function	Requirement	Requirement ID
1	To Transport	MOE: The SMART Stage shall transport personnel and their equipment to the worksite at operational depth under varying environmental conditions Metric: (Total personnel and equipment))/(Total weight) Threshold: 90% Goal: 100%	1
2	To Provide	MOE: The system shall monitor diver operations in all expected conditions Metric: (Support from the SMART Stage)/(User feedback) Threshold: 80% Goal: 100%	2
3	To Sense	MOE: The system shall be able to sense the environment the stage is used in Metric: (Accurate data)/(Position, Current, Salinity, Temperature) Threshold: 95% Goal: 100%	3
4	Usability	MOE: The system shall be capable of divers operating/learning how to operate on-the-job-training	4

Function ID	Function	Requirement	Requirement ID
		Metric: (SMART Stages that needed no contractor help)/(SMART Stages in use) Threshold: 80% Goal: 100%	
5	Re-use	MOE: The system shall be capable of re-use and re-located for the use on different platforms for different missions. Metric: (Total mission packages and locations the SMART Stage is capable of performing)/(Total packages) Threshold: 90% Goal: 100%	5
6	Reliability, Maintainability, Availability	MOE: The system shall be available for full operational use Threshold: 90% Goal: 100%	6

B. MEASURES OF PERFORMANCE

The measures of performance (MOP) relate to how well the functions must perform as measurable at the component level of the system. A MOP, shown in Table 4, is applied to the lowest level functions and is more defined in the terms on what the requirements shall meet.

Table 4. Requirements (Measure of Performance)

Function ID	Function	Requirement	Requirement ID
1.1	Personnel	MOP: The SMART Stage shall be able to transport three divers in their gear Metric: (Number of divers transported)/(Three divers) <u>Threshold: 100%</u> <u>Goal: 100%</u>	1.1
1.2	Equipment	MOP: The SMART Stage shall be able to transport the divers equipment up to 2700 pounds (includes divers weight) Metric: (Weight transported)/(2700 pounds) <u>Threshold: 100%</u> <u>Goal: 100%</u>	1.2
2.1	Services	MOP: The SMART Stage shall provide power and air <u>Threshold: TBR</u> <u>Goal: TBR</u>	2.1
2.1.1	Power	MOP: The SMART Stage shall provide power for the operational use of tools, illumination, and command & control <u>Threshold: 80%</u> <u>Goal: 100%</u>	2.1.1
2.1.1.1	Tools	MOP: The SMART Stage shall provide the power needed to run the tools (i.e., hydraulic, electrical, pneumatic) Metric: (Power provided)/(Tools operating) <u>Threshold: 80%</u> <u>Goal: 100%</u>	2.1.1.1
2.1.1.2	Environmental (Illumination)	MOP: The SMART Stage shall provide a 20 foot radius of illumination underwater (clean/clear water) Metric: (Distance of illumination)/(20 feet radius in clean/clear water) <u>Threshold: 90%</u>	2.1.1.2

Function ID	Function	Requirement	Requirement ID
		Goal: 100%	
2.1.1.3	Sensing Command & Control	MOP: The SMART Stage shall provide the power needed for sensors and command and control Threshold: 90% Goal: 100%	2.1.1.3
2.1.2	Air	MOP: The SMART Stage shall provide a steady supply of air for the divers to breathe Threshold: 100% Goal: 100%	2.1.2
2.2	Monitoring	MOP: The SMART Stage shall provide and maintain continuous information connectivity for monitoring situational awareness Metric: (Methods of information being provided)/(Information steadily provided) Threshold: 95% Goal: 100%	2.2
2.2.1	Image Collection & Transfer	MOP 1: The SMART Stage shall provide a continuous video stream to monitor the divers working at the site. MOP 2: The SMART Stage shall provide a continuous topographic image stream of the worksite. MOP 3: The SMART Stage shall provide a continuous video stream from helmet mounted cameras that are on the divers MOP 4: The SMART Stage mounted camera shall be controllable by the supervisor Metric: (Visual output/display from the SMART Stage)/(Sonar+Video) Threshold: 95% Goal: 100%	2.2.1–1 2.2.1–2 2.2.1–3 2.2.1–4

Function ID	Function	Requirement	Requirement ID
2.2.2	Data Collection & Transfer	MOP: The SMART Stage shall collect and transfer the environmental conditions sensed by the SMART Stage in operation Metric: (Data collected)/(Data requested) Threshold: 90% Goal: 100%	2.2.2
2.2.3	COMMS	MOP: The SMART Stage shall ensure that continuous voice communications are maintained between the diver and supervisor Threshold: 100% Goal: 100%	2.2.3
3.1	Depth	MOP: The SMART Stage shall be able to sense depth Metric: (Successful depth reading attempts)/(total # of depth reading request) Threshold: 95% Goal: 100%	3.1
3.2	Current	MOP: The SMART Stage shall be able to sense the water current at the depth of the stage Metric: (Successful current reading attempts)/(total # of current reading request) Threshold: 90% Goal: 100%	3.2
3.3	Temperature	MOP: The SMART Stage shall sense the temperature of the water at the stage location Metric: (Successful reading attempts)/(total # of reading request) Threshold: 90% Goal: 100%	3.3

VI. DESIGN CONCEPTS AND ALTERNATIVE SOLUTIONS

This chapter will identify the physical components allocated to functions to meet the requirements set. A morphological box method was utilized to organize and provide a basis for creating alternative possible physical solutions to the problem. The morphological box used in this thesis is in Appendix B. Each top level function is comprised of a sub-system that incorporates multiple components. Those components are mapped to the sub-functions and meet the requirements desired. Each alternative is investigated and analyzed to determine whether it is a feasible combination and to use as the basis for creating alternative designs to eventually find what the best option is for the U.S. Navy and the stakeholders involved.

What can be observed in Appendix B is that several of the possible components have been eliminated. This signifies that those components have been deemed infeasible or unusable; e.g., Function 2.1.1.1 Tools, has the options of nuclear and chemical stricken off because the ships the system is used on are not nuclear or chemically powered and having a portable nuclear/chemical power sources is not feasible. Some of the functions also have several components that have not been eliminated. These functions may need the use of all of these components to meet the functional requirements; e.g., Function 2.2.1 Image Collection & Transfer, has three components and each of those components meet the requirements.

A. PHYSICAL ARCHITECTURE TRADE-OFF

This section will determine the various physical components needed to create the SMART Stage along with what systems exist today that can meet the requirements set for the SMART Stage system. A component is a general category of a physical form of the design solution. A part is used as the specific name of an actual piece that can be procured as the component.

1. What Parts Are Needed to Meet the Requirements of the SMART Stage?

Prior to constructing the SMART Stage all of the necessary parts must be identified. Table 5 lists these various components that are needed to meet the SMART Stage requirements, along with the definitions of these components. These components will be able to operate at depths of 300 feet and withstand the various climates that the SMART Stage is requested to operate in.

Table 5. Component to Function Allocation & Definition

Function	Component	Definition
1.1	Stage	Is a platform that will transport personnel from the surface towards the underwater worksite
1.2	Stage	Is a platform that will transport equipment from the surface towards the underwater worksite
	Hoses	These are what power the tools and could be thrown overboard into the water directly to the diver
2.1.1.1	Hydraulic	The use of hydraulic fluids (oil) to create the power/pressure needed to run the tools
	Pneumatic	The use of compressed air to create the power/pressure needed to run the tools
	Electrical	The use of electricity to create the power needed to run the tools
2.1.1.2	Stage Mounted Lights	Lights mounted onto the top of the stage which will create the illumination needed
2.1.1.3	Wire	Material used to transfer information and power the equipment
	Fiber Optic	Material used to transfer information
2.1.2	Umbilical from ship	Series of hoses that transport breathing air for the divers
2.2.1	Acoustic topographic transceiver	A form of SONAR that will provide an image of the diver worksite

Function	Component	Definition
	Helmet mounted camera	Video cameras that are mounted to the divers' helmet which allows the supervisor to view what the diver sees
	Stage mounted camera	Video cameras that are mounted on the stage which allows the supervisor to scan the worksite. The camera is capable of tilt/pan/zoom giving the supervisor control of the image
2.2.2	Sensors attached to SMART Stage	The sensors used for data collection and transfer of current, temperature, and depth
2.2.3	Umbilical from ship	Series of hoses that transport breathing air for the divers along with an Audio/Visual hose for COMMS, a water hose, and Pneumatic air hose
3.1	Color coded chains	As a secondary means of determining the depth of the stage is having different color chains at certain distances. This will aide if the sensors malfunction
	Pressure sensor on stage	A pressure sensor that is attached to the stage will provide the depth of the SMART Stage. This will be the primary method of determining the depth
3.2	Argo (oceanography)	See Appendix C for details. This method will be the secondary method for providing needed data
	Current sensor attached to stage and transfers data back to the supervisor	Sensor attached to the SMART Stage that will collect and transfer data about the current to the supervisor. This is the primary method of collecting the data
3.3	Argo (oceanography)	See Appendix C for details. This method will be the secondary method for providing needed data

Function	Component	Definition
	Temperature sensor attached to stage and transfers data back to the supervisor	Sensor attached to the SMART Stage that will collect and transfer data about the temperature to the supervisor. This is the primary method of collecting the data
4	OJT	On the job training is when divers and supervisors will learn how to use the SMART Stage at their units and will not attend any schools for this training
	SMEs training at the units	Subject matter experts are people who are knowledgeable about the proper use of the SMART Stage, usually the creators, and train the divers/supervisors on how to use the system
5	Pre-Fabricated systems	SMART Stages that are already built by companies and ready for sale.
	COTS separate for transfer of what is needed on certain platforms	Commercial off-the-shelf parts used to build the SMART Stage. This setup allows the parts to be transferable and only what is needed at the time can be used
	COTS attached to one platform for transfer	Commercial off-the-shelf parts used to build the SMART Stage. This setup has all of the parts built into one system. This system is transferable but all of the components are attached and will be transferred

Other than the parts listed in Table 5, there is a need for a shipping container, also known as a CONEX Box, in order to make the SMART Stage meet all requirements given. This container will house the monitors needed for the video cameras, sensors, and is the overall command center for the dive supervisor. The CONEX Box is also utilized as storage locker for a portion of the divers’ gear and tools needed for the job. This CONEX Box is easily transported to the various worksites and can be placed aboard the different vessels that the U.S. Navy contracts/uses for the various diving operations.

To ensure that each function is met by a specific component a matrix was created, seen in Table 6. This matrix maps the components to the functions listed and allows readers to visualize this mapping. Every function must have at least one component assigned, however, a single component can map to multiple functions. This allows a system to be streamlined but could cause issues if a component were to fail due to the overdependence on that component.

Table 6. Component to Function Mapping

		FUNCTIONS													
		1.1	1.2	2.1.1.1	2.1.1.2	2.1.1.3	2.1.2	2.2.1	2.2.2	2.2.3	3.1	3.2	3.3	4	5
COMPONENT	Stage	x	x												
	Hoses		x												
	Hydraulic			x											
	Pneumatic			x											
	Electrical			x											
	Stage Mounted Lights				x										
	Wire					x									
	Fiber Optic					x									
	Umbilical from ship						x			x					
	Acoustic topographic transceiver							x							
	Helmet mounted camera							x							
	Stage mounted camera							x							
	Sensors attached to SMART Stage								x						
	Color coded chains										x				
	Pressure sensor on stage										x				
	Argo (oceanography)											x	x		
	Current sensor attached to stage and transfers data back to the supervisor												x		
	Temperature sensor attached to stage and transfers data back to the supervisor												x		
	OJT													x	
	SMEs training at the units													x	
	Pre-Fabricated systems														x
	COTS separate for transfer of what is needed on certain platforms														x
	COTS attached to one platform for transfer														x

Once it has been determined that each function is mapped to a component, a list of alternative parts is made. This is a list of the possible parts available that can meet the requirements given and are mapped to the components. In Table 7, the alternative parts listed are COTS which means they are available for purchase by the Navy and can be installed on the current dive stages transforming them into the SMART Stage. Within the column labeled MOP a metric, form of grading scale, is annotated. This metric will grade the part on whether it meets the requirements set, discussed later in detail in Chapter VII.

Some of the components listed in Table 6 are not analyzed in Table 7 due to them being a form of redundancy for the SMART Stage system, an example being color coded chains.

Table 7. Part Alternative

Component	Alternative Parts	MOP
Stage Mounted Lights	Snooper II 5567	H:1, M:0.6, L:0
	Snooper III	
Umbilical from ship	Divers Supply 4 member twist	H: 1, M: 0.6, L: 0
	Divers Supply 3 Member Twist	
	Amron International 650 ft. Military 4-Part Spiral Diving Umbilical with Oxygen Fittings and Navy 5-Pin Male MS Surface Connector	
	Fibron Umbilical	
Acoustic topographic transceiver	IMAGENEX Digital Multi-Frequency Imaging Sonar	H: 1, M: 0.6, L: 0
	Blue View BV5000 3D Mechanical Scanning Sonar	
	Kongsberg Maritime Search and Recovery Systems	
	Tritech SeaKing Hammerhead	
Helmet mounted camera	Use Current Models	
Stage mounted camera	Kongsberg Maritime OE14-122/123	H: 1, M: 0.6, L: 0
	Kongsberg Maritime OE14-522	
	Rovsco Maximuz-3000	
Pressure sensor on stage	Paroscientific 8DP	H: 1, M: 0.6, L: 0
	Paroscientific 181KT	
	Global Water WL400 Water Level Sensor	
	Stevens Greenspan PS 2100	
	Oceaneering DTS Intelligent Pressure Transducer	
Current sensor attached to stage and transfers data back to the supervisor	Valeport Model 803 ROV Electromagnetic current meter	H: 1, M: 0.6, L: 0.3
Temperature sensor attached to stage and transfers data back to the supervisor	Paroscientific 181KT	H: 1, M: 0.6, L: 0.3
	Stevens Greenspan PS 2100	
	Oceaneering DTS Intelligent Pressure Transducer	

2. What Are Some of the Commercial Pre-Fabricated Dive Stages That Meet the Requirements of the SMART Stage?

This section will conduct an analysis of four companies which produce commercial diving stages called Launch and Recover System (LARS). The LARS is a system which is transportable and contains a crane, stage, and the hydraulics needed to operate the equipment. The four companies are Unique Hydra, Pommec, SMP Hydraulic, and IHC Hytech. Table 8 compares the attributes of various systems these companies offer for sale against the components needed for the SMART Stage.

Table 8. Pre-Fabricated Stage System Analysis

	Unique Hydra LR 50 A2	Pommec 2 Diver LARS Heavy Duty	SMP Hydraulic Diver LARS	IHC Hytech LARS
Stage	2 Divers	2 Divers	2 Divers	2 Divers
Stage Mounted Lights	None	None	None	None
Umbilical from ship	Yes	Yes	Yes	Yes
Acoustic topographic transceiver	None	None	None	None
Helmet mounted camera	Yes	Yes	Yes	Yes
Stage mounted camera	None	None	None	None
Sensors attached to SMART Stage	None	None	None	None
Color coded chains	None	None	None	None
Pressure sensor on stage	None	None	None	None

	Unique Hydra LR 50 A2	Pommec 2 Diver LARS Heavy Duty	SMP Hydraulic Diver LARS	IHC Hytech LARS
Current sensor attached to stage and transfers data back to the supervisor	None	None	None	None
Temperature sensor attached to stage and transfers data back to the supervisor	None	None	None	None
Extra Information	This is a deployable system. This system contains a stage built from an A-frame. The entire system is coated for sea air and water to prevent corrosion. The system includes a 1-ton divers winch that has 80 meters of cable and a guide wire winch with 160 meter of cable. This is system is comprised of only the winch and stage.	This is a deployable system which contains the stage, winch, frame, and power needed to operate the system. The max depth of the stage is 100 meters and there is a clump weight winch with 200 meters of cable. The stage is capable of holding 500 kg and the clump weight cable is capable of holding 400 kg.	This is a deployable system. The system has an A-Frame assembly with a stage for two divers. There are two hydraulic powered winches: one for the stage and the other is for the clump weight. The system also is equipped with the power unit needed to run the winches. The max depth of the stage is 75 meters.	This is a deployable system. It has a two person stage equipped with two 50 liter air bottles. The max depth is 100 meters. The system is capable of operating in temperatures ranging from -4 to 122 degrees Fahrenheit.

As seen in Table 8, neither of these companies is capable of providing the components needed for the SMART Stage. The two components that they do provide are umbilical and helmet mounted cameras and this is due to those components being separate from the system and provided by the divers themselves.

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VII. EFFECTIVENESS ANALYSIS

This chapter will discuss the method used in analyzing whether the functions and requirements set for the SMART Stage were met by each part as well as indicating the grade each part received.

A. HOW ARE THE BENEFITS DEFINED FOR A SMART STAGE?

As stated in the previous chapter MOPs were assigned to each part to determine its measure of performance for the SMART Stage. For a part to receive a MOP of 1, that part must achieve the required goal set by the requirements and has additional uses that make it a better choice. A part receives an MOP of 0.6 when it also meets the goal; however, it lacks the additional features when compared to the part which received a MOP of 1. A part will receive a MOP of 0 when it meets the threshold and just barely meets the desired performance. Some parts also received a MOP of X and this is due to them not meeting at least the threshold value for the requirements set, as seen in Table 9.

Table 9. Effectiveness Analysis of Parts

Component	Alternative Parts	MOP
Stage Mounted Lights	Snooper II 5567	M
	Snooper III	H
Umbilical from ship	Divers Supply 4 member twist	L
	Divers Supply 3 Member Twist	X
	Amron International 650 ft. Military 4-Part Spiral Diving Umbilical with Oxygen Fittings and Navy 5-Pin Male MS Surface Connector	M
	Fibron Umbilical	H
Acoustic topographic transceiver	IMAGENEX Digital Multi-Frequency Imaging Sonar	L
	Blue View BV5000 3D Mechanical Scanning Sonar	M
	Kongsberg Maritime Search and Recovery Systems	L
	Tritech SeaKing Hammerhead	H
Helmet mounted camera	Use Current Models	H

Component	Alternative Parts	MOP
Stage mounted camera	Kongsberg Maritime OE14-122/123	M
	Kongsberg Maritime OE14-522	H
	Rovsco Maximuz-3000	L
Pressure sensor on stage	Paroscientific 8DP	L
	Paroscientific 181KT	H
	Global Water WL400 Water Level Sensor	L
	Stevens Greenspan PS 2100	M
	Oceaneering DTS Intelligent Pressure Transducer	M
Current sensor attached to stage and transfers data back to the supervisor	Valeport Model 803 ROV Electromagnetic current meter	H
Temperature sensor attached to stage and transfers data back to the supervisor	Paroscientific 181KT	H
	Stevens Greenspan PS 2100	M
	Oceaneering DTS Intelligent Pressure Transducer	M

An example of the analysis taken to determine whether a particular part received an MOP of H, M, or L is shown in Table 10. There were three brands of cameras, being analyzed, that had met the initial requirement of functioning at a depth of 300 feet or greater. Once the cameras were determined operational at the required depths, they were then evaluated against the other requirements as well as among themselves. From this analysis, it was decided that the Kongsberg Maritime OE14-522 would be the ideal choice because of the high horizontal resolution it provided. Horizontal resolution is the clarity of the image meaning higher the number better the image.

Table 10. Effectiveness Analysis of the Camera

Camera									
Company NAME	**Product Name**	**Price**	**Color**	**Pan**	**Tilt**	**Zoom**	**Depth(meters)**	**Lux(face plate sensitivity)**	**Horizontal Resolution(TV Lines)**
Kongsberg Maritime	OE14-122/123		yes	yes	yes	yes	3000	0.02	460-470
Kongsberg Maritime	OE14-522		yes	yes	yes	yes	4500	0.1	800
Rovsco	Maximuz-3000		yes	no	no	yes	3000	1	470

For the detailed analysis as to why a particular part received and M instead of an H please refer to Appendix D.

B. RESULTS AND RECOMMENDATIONS

Of the four analyzed pre-fabricated stages none of the systems contained any components that are needed to create the SMART Stage. From this analysis, none of these systems would provide the value needed to meet the needed SMART Stage capabilities for the U.S. Navy unless they wanted a system with a crane that was separate from what the salvage ships provided. If a system were to be purchased, then out of the four different systems, only two are capable of operating in the depths needed for the divers: the LARS from IHC Hytech and Pommec. In order for these systems to meet the functions and requirements of the SMART Stage, the purchase and installation of COTS parts will still be needed.

The final design for the SMART Stage is a system that is comprised of the COTS parts, identified in Table 11, along with a CONEX Box to serve as the command center for the dive supervisor. The COTS parts would be installed onto every dive stage used by the Navy and connected to the command center. These connections could be on a separate pulley from the cable/chain used to raise and lower the stage but they will have to move along with the stage as it is raised and lowered. In addition, with the sensors being attached onto the stage, extra sources will be utilized to serve as a backup which will create a redundancy for the SMART Stage. These extra sources are: color-coded chains to help identify the depth of the stage and ARGO, described in Appendix C, utilized to help provide additional information of the temperature at various depths (UCSD 2013). The power sources for the tools are separate pumps and generators that will be housed in the command center. An additional feature of a hose reel or toll box could be added to the stage; this would allow the divers access to other tools not otherwise known ahead of time to complete the task at hand.

Table 11. Recommended Parts

Component	COTS Parts
Stage Mounted Lights	Snooper III
Umbilical from ship	Fibron Umbilical
Acoustic topographic transceiver	Tritech SeaKing Hammerhead
Helmet mounted camera	Use Current Models
Stage mounted camera	Kongsberg Maritime OE14-522
Pressure sensor on stage	Paroscientific 181KT
Current sensor attached to stage and transfers data back to the supervisor	Valeport Model 803 ROV Electromagnetic current meter
Temperature sensor attached to stage and transfers data back to the supervisor	Paroscientific 181KT

It was determined that the umbilical should be separate from the stage, as it already is, for the following reason: if extra divers are needed to operate at the site, then the stage must be lifted back to the surface, and if the umbilical was attached to the stage, then that would cause a hindrance and the only solution to that would be to provide extra umbilical length for the diver's bellow. This would cause an increase in weight for the stage as well as take up valuable space on the deck of the ship.

Also it is recommended that hydraulics not be pumped through the umbilical. Reasoning behind this is that at times hydraulic hoses may burst and if such an occurrence were to happen, then the diver must be removed from the site back to the surface for repairs to the umbilical which would slow down production. Along with not combining hydraulic hoses with the umbilical, the U.S. Navy should minimize its use of hydraulic tools as they pose a hazardous threat to the environment if malfunction were to occur. The recommended COTS parts, as seen in Table 11, have not been priced due to the unavailability of that information because it required contacting the providers and providing them potential orders, which this author was not authorized to do.

VIII. CONCLUSION

From the analysis conducted within the thesis, the SMART Stage shall be a system comprised of the components listed in Table 5. These components meet the requirements of the system and are able to conduct the functions identified from the needs of the stakeholders. The Navy should not purchase and pre-fabricated dive stage systems unless they contain the components identified. The recommended COTS parts are what the Navy can readily purchase and install onto their existing dive stages which will convert them into SMART Stages.

Throughout this thesis the Systems Engineering process and modeling was used in developing the solutions. This process consisted of an extensive research on the current dive stage in use today, a detailed analysis of the stakeholders and their needs, identifying the functions and requirements, a look at various design concepts, which all resulted into the final recommendations of the SMART Stage. This thesis had focused on the "down stroke" of the Vee model and it is up the program managers to take this analysis and complete the "upstroke" of the Vee model. The way ahead for the SMART Stage is to conduct a cost-benefit analysis of the parts and system, test the parts, verify they work together as a system, and provide the SMART Stage to all the dive lockers.

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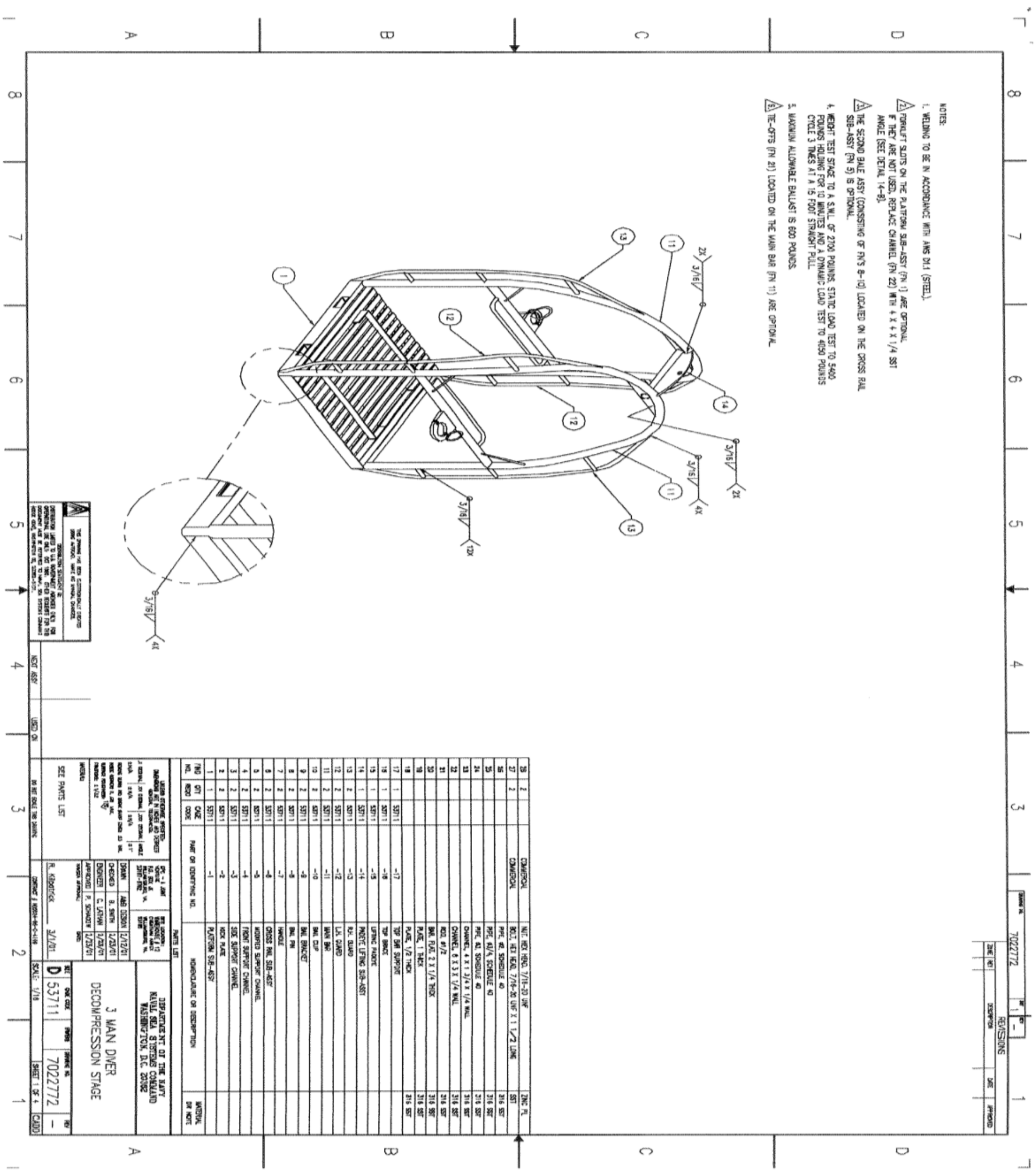
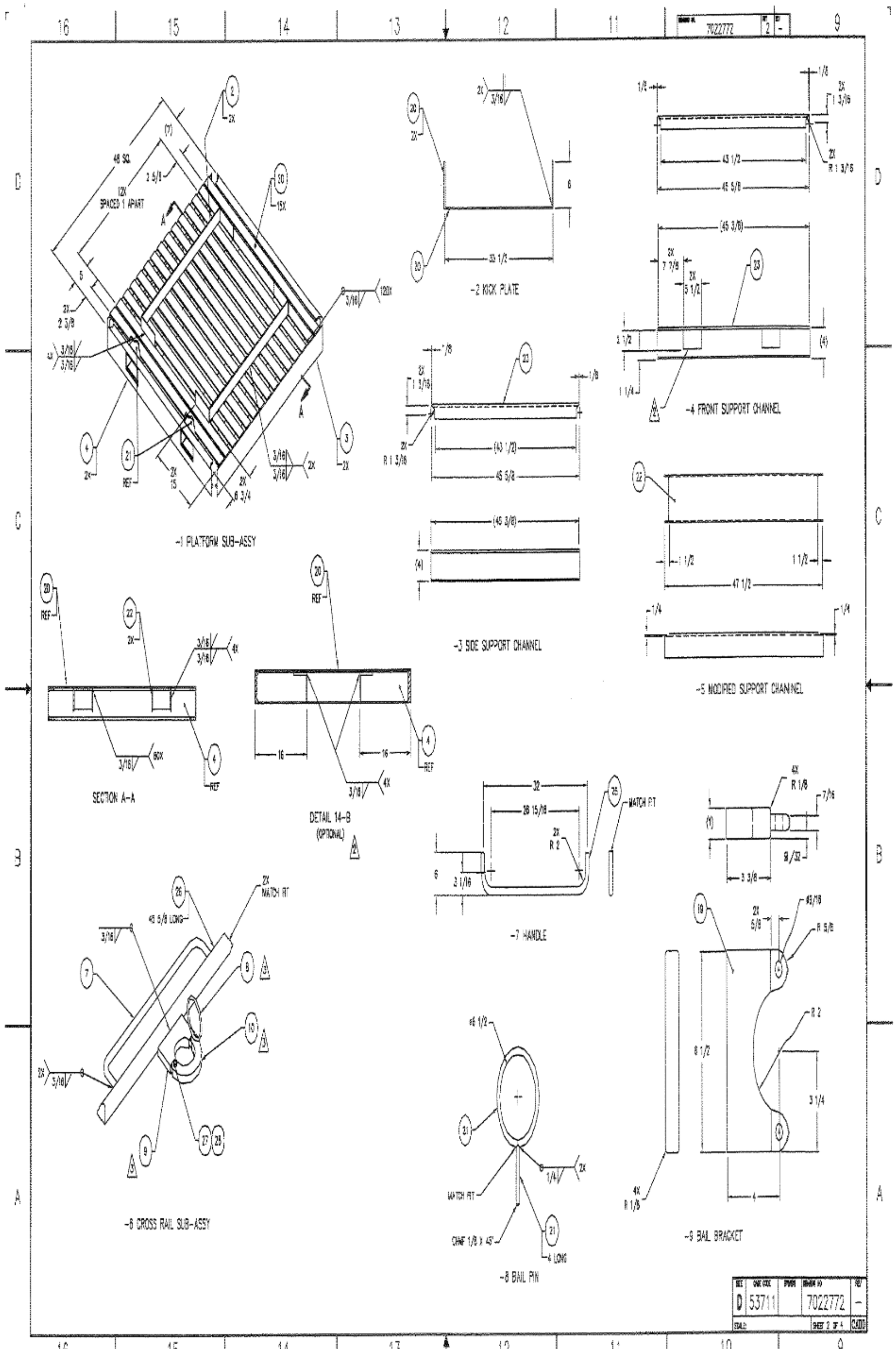
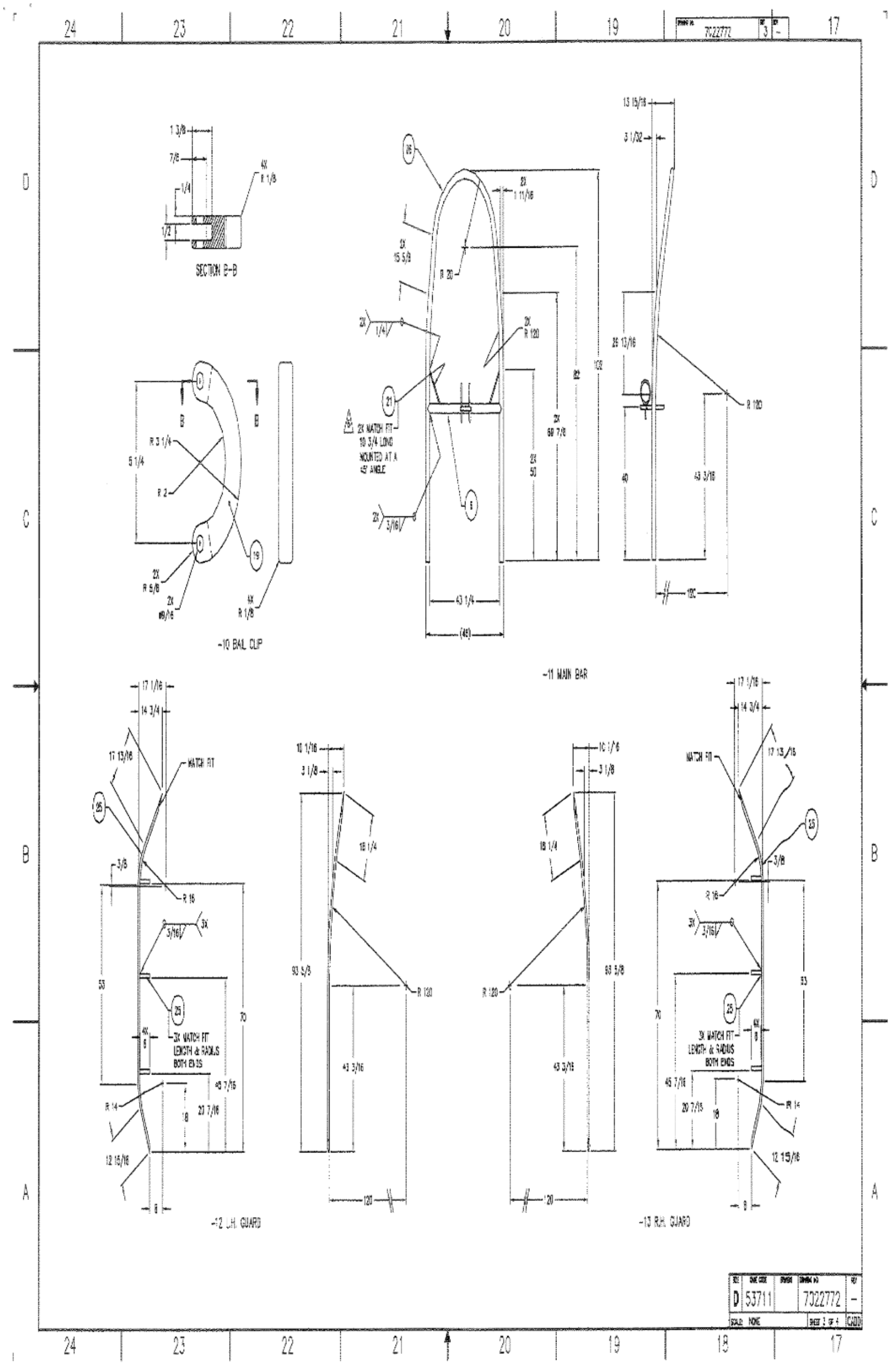
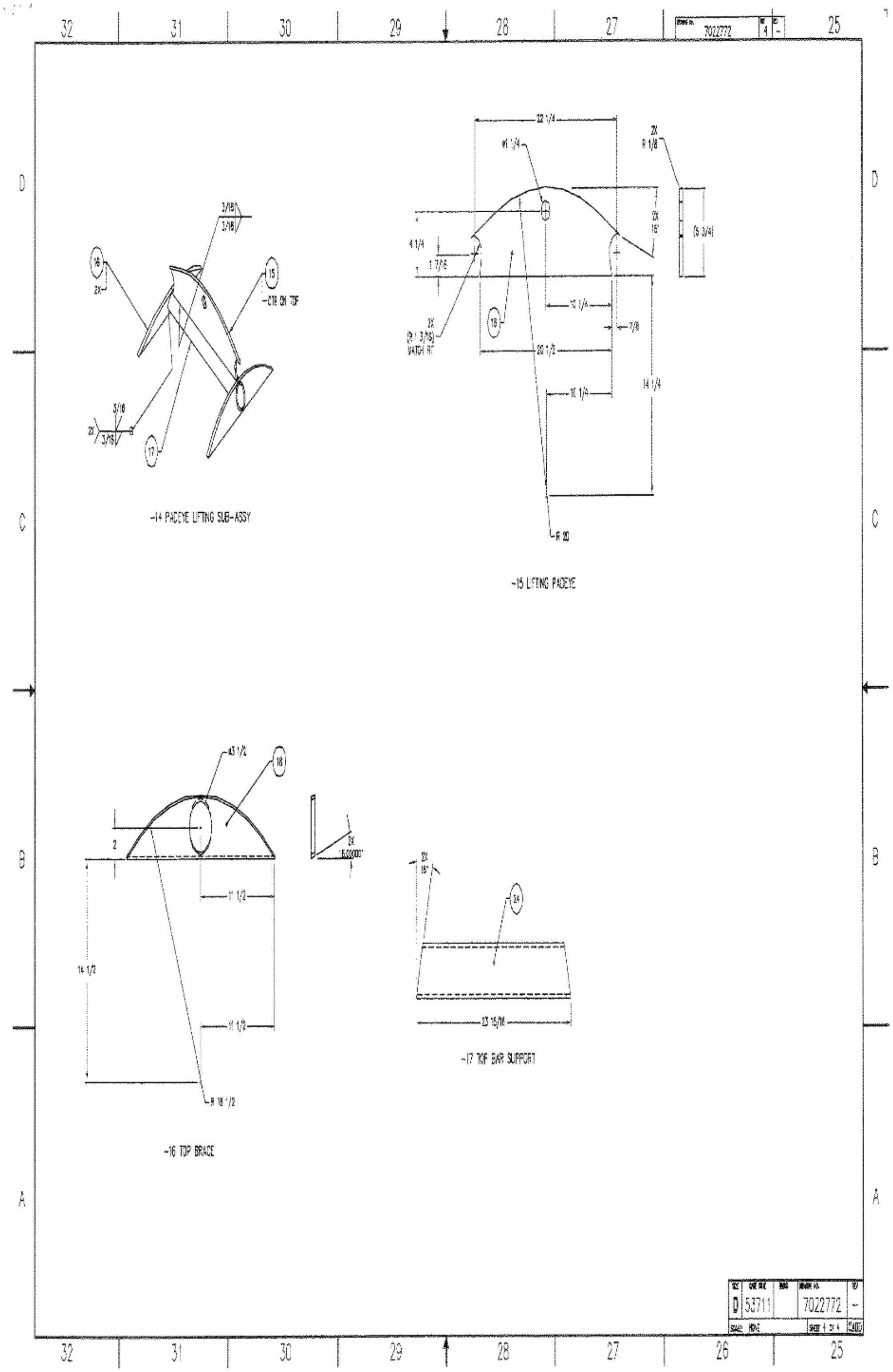
APPENDIX A. DIVE STAGE DIAGRAM




-1 PLATFORM SUB-ASSY
-2 KICK PLATE
-3 SIDE SUPPORT CHANNEL
-4 FRONT SUPPORT CHANNEL
-5 MODIFIED SUPPORT CHANNEL
SECTION A-A
DETAIL 14-B (OPTIONAL)
-7 HANDLE
-6 CROSS RAIL SUB-ASSY
-8 BAIL PIN
-9 BAIL BRACKET
D 53711 7022772


SECTION B-B
-10 BAIL CLIP
-11 MAIN BAR
-12 L.H. GUARD
-13 R.H. GUARD
2X MATCH FIT 10 3/4 LONG MOUNTED AT A 45° ANGLE
2X MATCH FIT LENGTH & RADIUS BOTH ENDS
3X MATCH FIT LENGTH & RADIUS BOTH ENDS
MATCH FIT
D 53711 7322772
SCALE: NONE



-14 PADEYE LIFTING SUB-ASSY
-15 LIFTING PADEYE
-16 TOP BRACE
-17 TOP BAR SUPPORT
7022772
53711

APPENDIX B. MORPHOLOGICAL BOX

0.0 To Assist in Missions
SMART Stage

1.0 To Transport
Transport Subsystem

1.1 Personnel	1.2 Equipment
Stage	Stage
~~Cable~~	~~Cable~~
~~Rope~~	~~Rope~~
~~Free Dive~~	Hoses (what the tools are powered by)

2.0 To Provide
Provide Subsystem

2.1 Services
Service Subsystem

2.1.1 Power
Power Subsystem

2.1.2 Air
SCUBA
Umbilical from ship
~~Umbilical from tanks on stage~~
~~Umbilical connected to stage which is connected to the ship~~

2.1.1.1 Tools	2.1.1.2 Environmental (Illumination)	2.1.1.3 Sensing Command & Control
Hydraulic	~~Hand held lights~~	~~Acoustic~~
Pnuematic	~~Helmet mounted lights~~	Wire
Electrical	~~Hull mounted lights~~	Fiber optic
~~Nuclear~~	Stage mounted lights	
~~Chemical~~		

2.2 Monitoring
Monitoring Subsystem

2.2.1 Image Collection & Transfer	2.2.2 Data Collection & Transfer	2.2.3 COMMS
Acoustic topographic transceiver	~~Diver reported~~	Umbilical
Helmet mounted camera	Sensors attached to Smart Stage	~~Underwater phone~~
Stage mounted camera	~~Expendable sensors (bathythermograph)~~	

3.0 To Sense
Sense Subsystem

3.1 Depth	3.2 Current	3.3 Temperature
Color coded chains	~~Expendable sensor (bathythermograph)~~	~~Expendable sensor (bathythermograph)~~
~~Depth markers on the umbilical~~	Argo (oceanography)	Argo (oceanography)
~~Pressure sensor on diver~~	Current sensor attached to the stage and transfers data back to the supervisor	~~Thermometer attached to diver and read back to the supervisor~~
Pressure sensor on stage	~~Current sensor attached to the ship~~	~~Thermometer attached to the stage and read back to the supervisor via diver~~
~~Diver relays depth on his personnel sensor~~	~~Current sensor attached to the stage and read back to the supervisor via diver~~	Thermometer attached to the stage and transfers data back to the supervisor
~~Expendable sensor (bathythermograph)~~		

4.0 Usability
OJT
Subject Matter Experts training at the units
~~Training at dive school~~
~~Extra school for users~~

5.0 Re-Use
Pre-Fabricated systems
COTS separate for transfer of what is needed on certain platforms
COTS attached to one platform for transfer

APPENDIX C. ARGO OCEANOGRAPHY

Argo consists of 3,000 free-drifting floats that measure the temperature and salinity of the ocean at depths of 2000 meters. The floats ascend from the depth of 2k meters every 10 days, and stays afloat for less than a day, reporting its finding of the salinity and temperature that it collected from its ascend, seen in Figure 5. The data is free for the public and there are over 50 research agencies from over 30 countries that participate in the maintenance of the floats and use of the data. The floats have a life span of five years and once they expire they are designed to sink to the ocean floor (UCSD 2013).

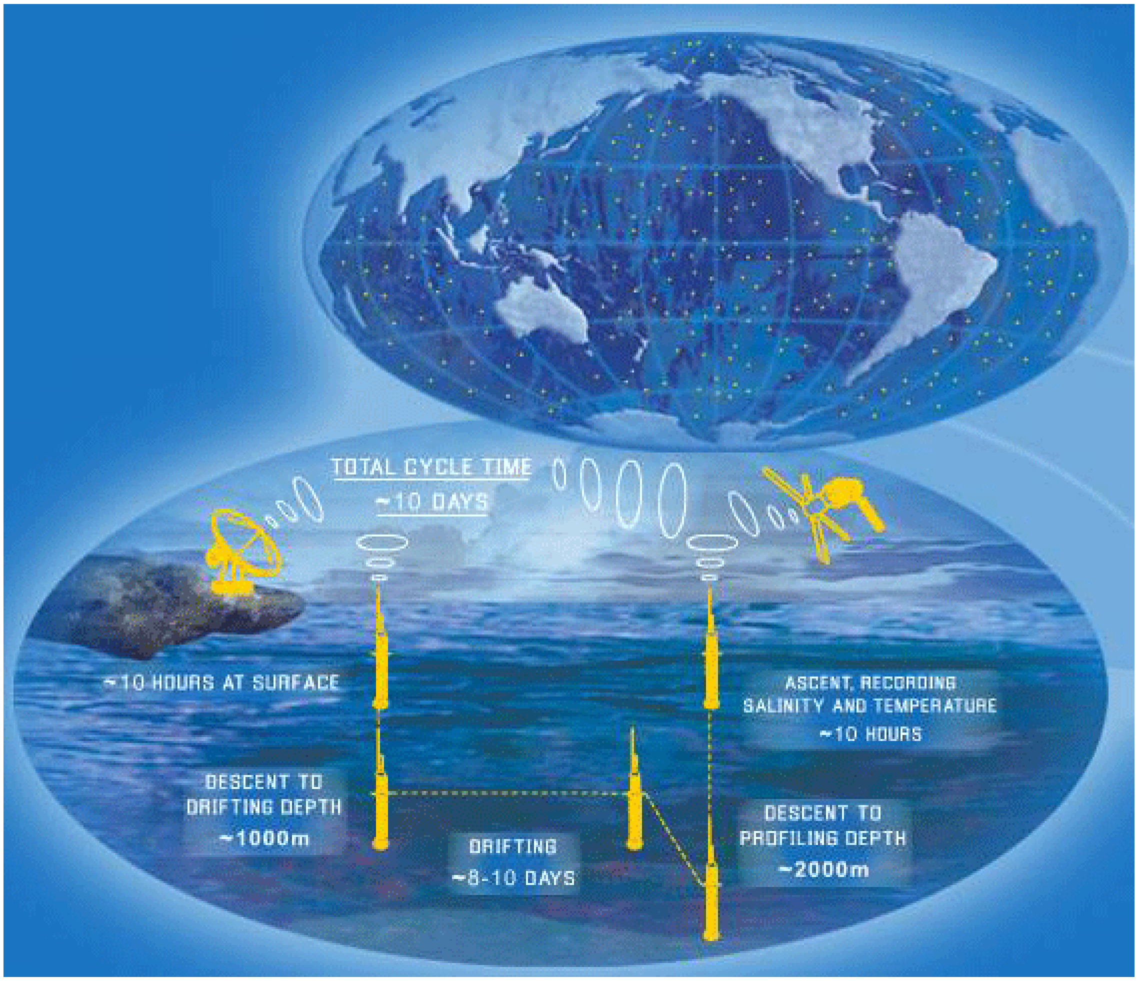


Figure 5. ARGO Float Process (From AIC 2013)

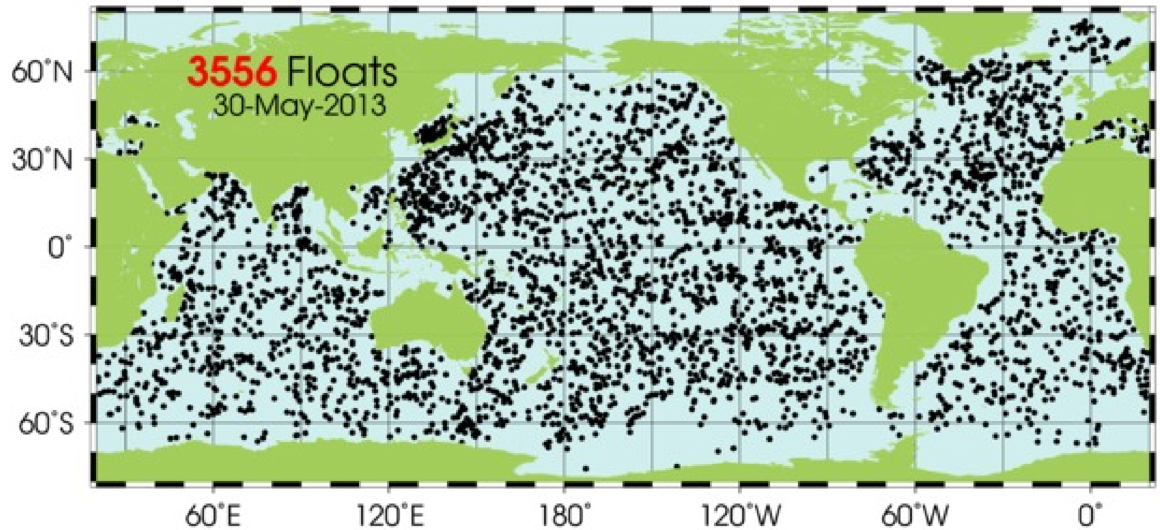


Figure 6. Location of ARGO Floats (From UCSD 2013)

APPENDIX D. PART SELECTION

The following images are screen shots of the Excel file used to identify the various attributes of each part. Depending on whether the parts meet the requirements given determined the MOP score they had received. Parts highlighted in green received an MOP of 1, yellow highlighted parts received an MOP of 0.6, and parts highlighted in red received either a 0 or a X.

Umbilical

Company NAME	Product Name	Price	Length	Air	Water	Comms	Video	Pneumo	Hydraulics
Divers Supply	4 member twist		they make it to your desired length	Yes	No	Yes	Yes	Yes	No
Divers Supply	3 Member Twist		they make it to your desired length	Yes	No	Yes	No	Yes	No
Amron International	Amron International 650 ft. Military 4-Part Spiral Diving Umbilical with Oxygen Fittings and Navy 5-Pin Male MS Surface Connector	9430.14	650	Yes	Yes	Yes	Yes	Yes	No
Cortland Company	Fibron Umbilical	They can make any length and fittings for umbilical		Yes	yes	yes	yes	yes	yes

Camera

Company NAME	Product Name	Price	Color	Pan	Tilt	Zoom	Depth(meters)	Lux(face plate sensitivity)	Horizontal Resolution(TV Lines)
Kongsberg Maritime	OE14-122/123		yes	yes	yes	yes	3000	0.02	460-470
Kongsberg Maritime	OE14-522		yes	yes	yes	yes	4500	0.1	800
Rovsco	Maximuz-3000		yes	no	no	yes	3000	1	470

Sonar

Company NAME	Product Name	Price	Depth(Meter)	Range(meter)
IMAGENEX	Digital Multi-Frequency Imaging Sonar	10,000-12,000	1000 or 3000	200
Blue View	BV5000 3D Mechanical Scanning Sonar		300 or 4000	10-30 meters
Kongsberg	Search and Recovery Systems		650-6000	40-200
Tritech	SeaKing Hammerhead		700 or 4000	100
Company NAME	**Interface**	**Sector Size**	**Image Quality/display**	**Pan/Tilt**
IMAGENEX	Ethernet	0-357 in 3 degree increments	typical sonar image(blob on a screen)	no-it is continous scan or sector scan
Blue View	Ethernet	45-360 degree	3D picture type	yes you can control
Kongsberg	Ethernet	360	typical sonar image(blob on a screen)	no-it is continous scan or sector scan
Tritech	Ethernet	360	Horizontal-typical sonar image(blob on a screen), vertical- 3d picture like	no-it is continous scan or sector scan

Lighting

Company NAME	Product Name	Price	Depth(meters)	Watts	Lumens	Recent Model
Birns	Snooper II 5567	1695	3000	600-1000	17000-28000	NO
Birns	Snooper III		3000	400-1200	10000-33000	yes

Depth Sensor

Company NAME	Product Name	Price	Depth	Reading Accuracy	Temperature	Interface
Paroscientific Inc	8DP		700	0.01%	No	RS232
Paroscientific Inc	181KT		700	0.02%	Yes	RS232
Global Water	WL400 Water Level Sensor		152.4	0.10%	no	RS232
Stevens	Greenspan PS 2100	1770	100	0.10%	Yes	rs232 and memory stick
Oceaneering DTS	Intelligent Pressure Transducer		3048	0.05%	Yes	RS232

Current Sensor					
Company NAME	Product Name	Price	Depth(meters)	Interface	Accuracy
Valeport	Model 803 ROV Electromagnetic current meter		500-4000	RS232	.02kts

Depth & Current Display					
Company NAME	Product Name	Price	Depth	Current	Temperature
Paroscientific Inc	Model 715		y*		y

LIST OF REFERENCES

Argo Information Center (AIC), "Argo.net," May 30, 2013, http://www.argo.net/.

Blanchard, Benjamin S., and Wolter J. Fabrycky. 2011. *Systems Engineering And Analysis.* Upper Saddle River, NJ: Prentice Hall.

Commander, Naval Sea Systems Command. 2011. *U.S. Navy Diving Manual*. Washington, DC: U.S. Goverenment Printing Office.

University of California San Diego (UCSD), "Argo: Part of the Integrated Global Observation Strategy," May 30, 2013, http://www.argo.ucsd.edu/.

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